Jet Propulsion Laboratory
California Institute of Technology

Mars Ascent Vehicle Concept – Overview and Aeroheating/Thermal Protection System Design

Marcus Lobbia[1]

Co-Authors: Ashley Korzun,[2] Joel Benito,[1] and Robert Shotwell[1]

[1] Jet Propulsion Laboratory, California Institute of Technology

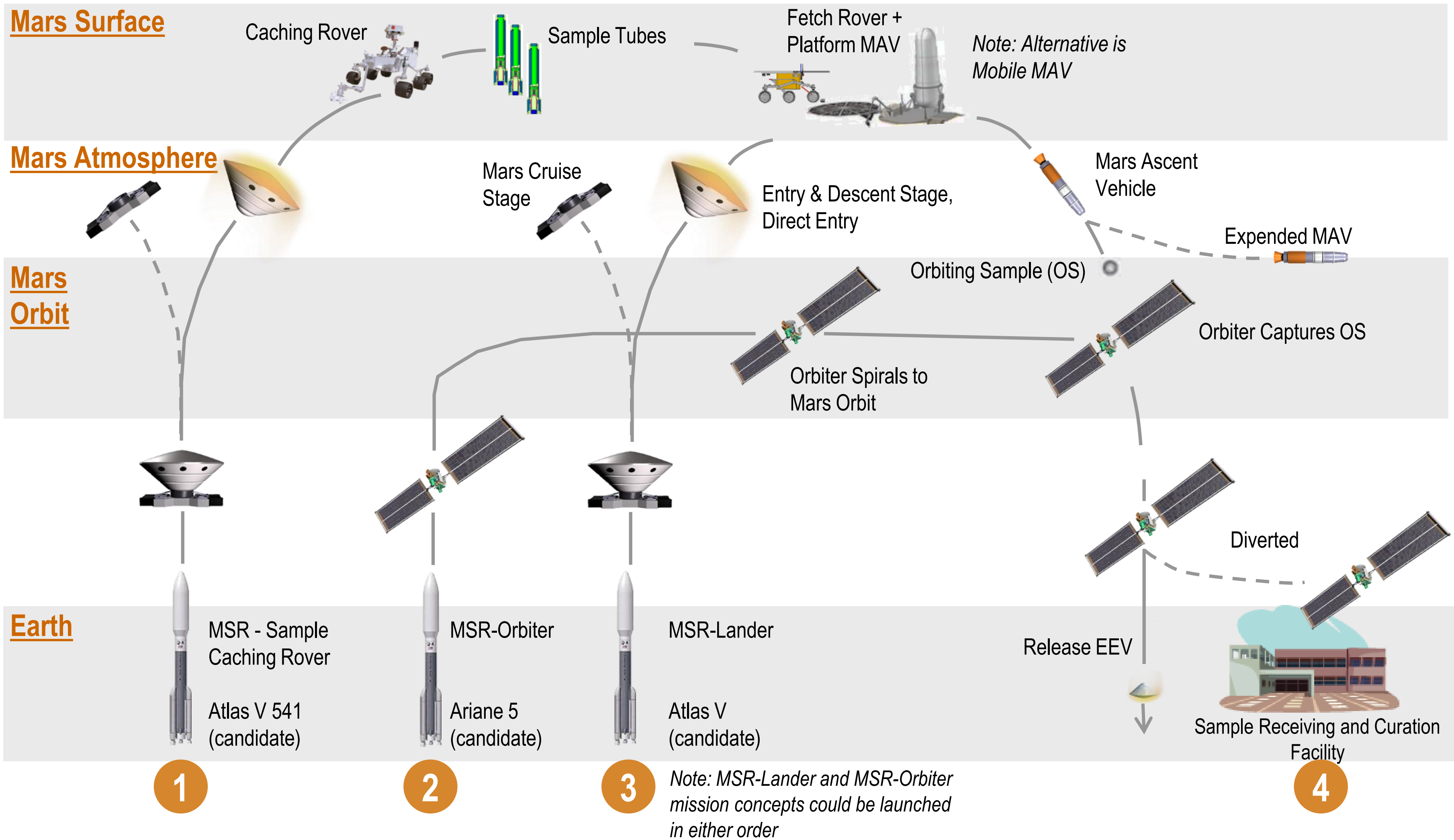
[2] NASA Langley Research Center

Introduction

- Significant progress toward Mars Sample Return (MSR) identified as one of the highest-priority goals in the Planetary Sciences Decadal Survey (2011)
- NASA and JPL are conducting development activities to mature MSR-related technologies
  - Sampling system design trades
  - Mars Ascent Vehicle (MAV) concept design trades
  - MAV Lander concept design trades
  - and more…

Objective: Provide an overview of the MAV design space, with a focus on recent aeroheathing/TPS design trades

Potential Mars Sample Return – Notional Architecture

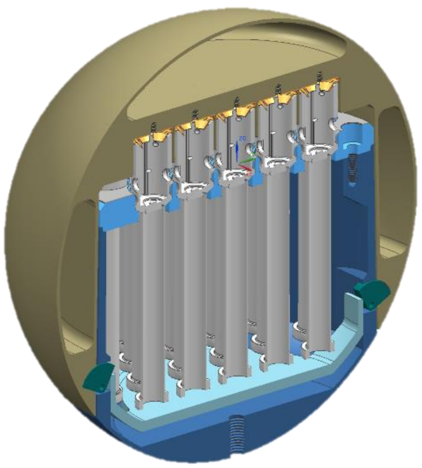


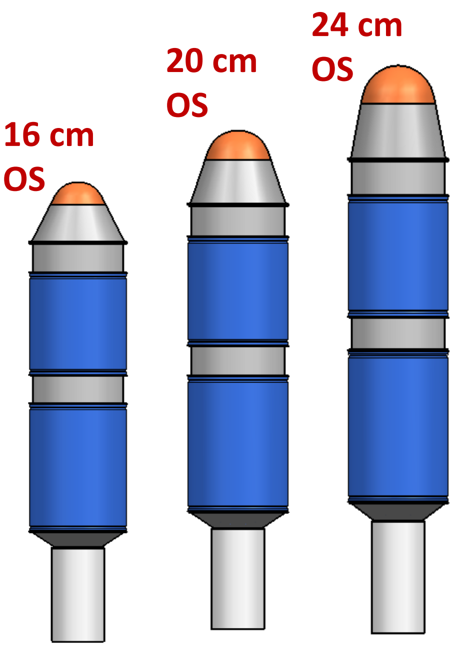
MAV Studies Tradespace

- Lander Trades
  - Mobile MAV vs Fetch Rover
    - Affects packaging volume and mass
  - RTG vs Solar Power
    - Affects MAV thermal limits and lander power /energy reqs
- Mission Trades
  - Landing site and target altitude (site for Mars 2020 will be chosen by Science)
  - Size of payload (will be driven by Mars 2020 tube design and additional requirements assigned to OS)
- MAV trades
  - Type of prop to use (solids, hybrids, liquids)
  - RCS approach (cold gas, warm gas, passive stabilization, mixed)
  - Internal redundancy (single string vs selected redundancy vs block)
  - Staged vs SSTO
  - Faired or direct payload
  - Vertical vs inclined launch

Orbiting Sample Concept

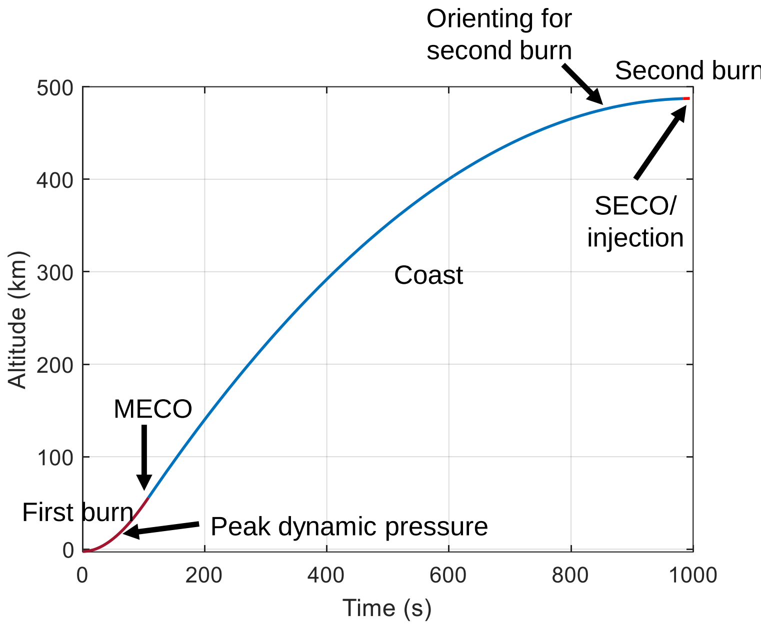
- The payload for the MAV would be the Orbiting Sample (OS)
- The OS is assumed to be mounted to the MAV when it departs from Earth
- As the number and size of samples to be returned grows, the OS grows as well
  - Drives MAV size and mass
- MAV assumes Thermal Protection System (TPS) material on forward hemisphere
  - No Fairing

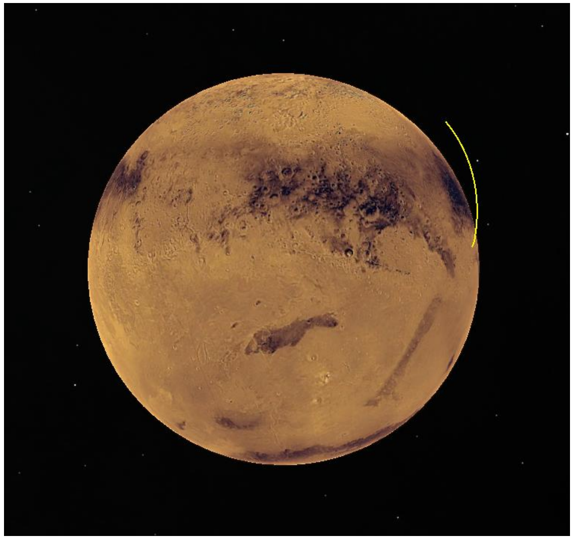




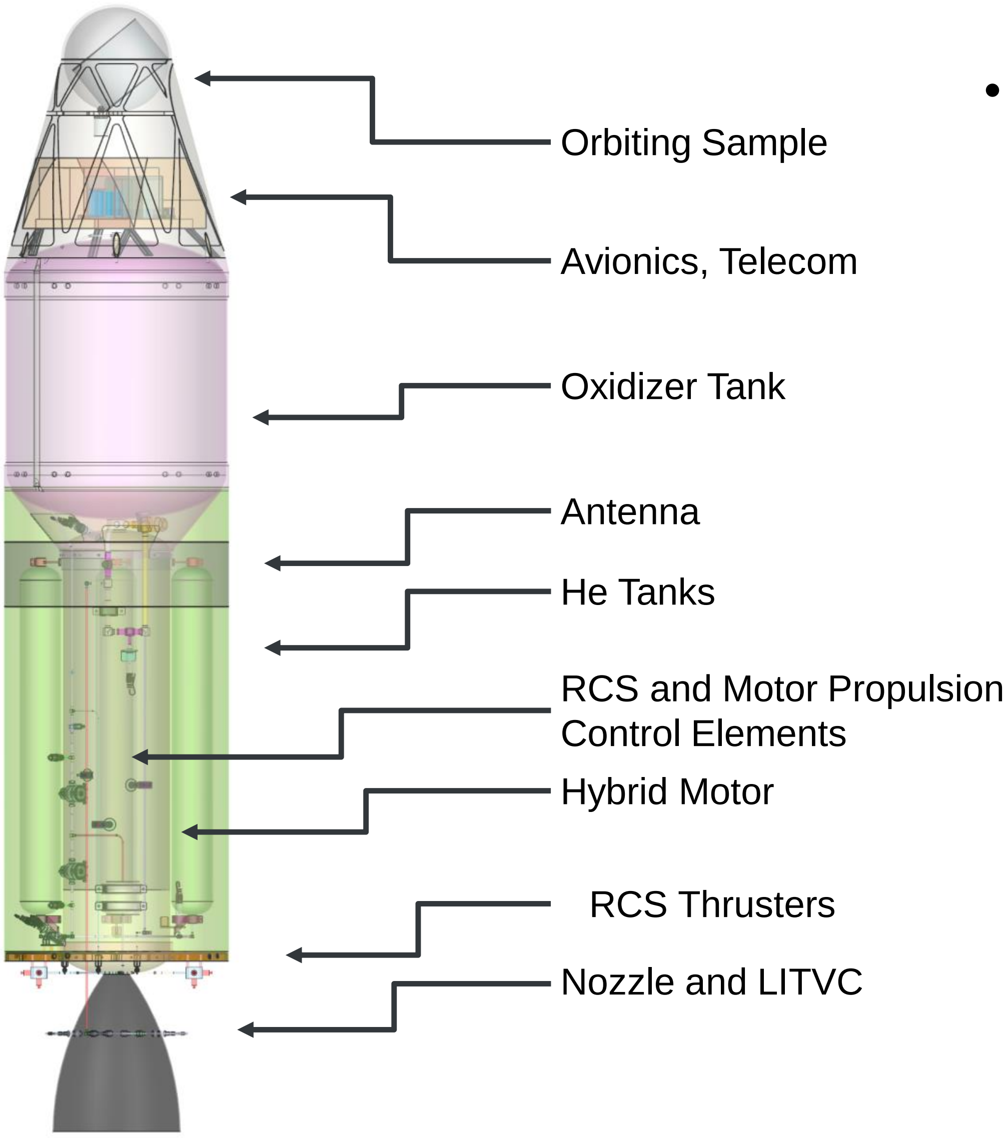
MAV Mission Concept Definition

- Mission concept objectives and constraints:
  - Consider candidate M2020 landing sites
    - Launch from any latitude $|\phi|<30$ deg
    - Launch from any elevation > -2.5 km
  - Inject OS into a 479x479 km altitude orbit,
    - Periapse altitude above 300 km altitude, to ensure at least a decade of orbital lifetime and reduce requirements on rendezvous orbiter
- Mission concept phases:
  - Pre-launch: warm up, OS loading, erection, system initialization, pyros fired
  - Liftoff: full thrust, climb until clearing the launch tube
  - First burn: trajectory steered using Thrust Vector Control (TVC) to aim at target Main Engine Cut Off (MECO) conditions
  - Coast: unpowered flight; vehicle controlled with RCS
  - Second burn: orbit circularization/injection
  - OS release
  - Post release maneuvers





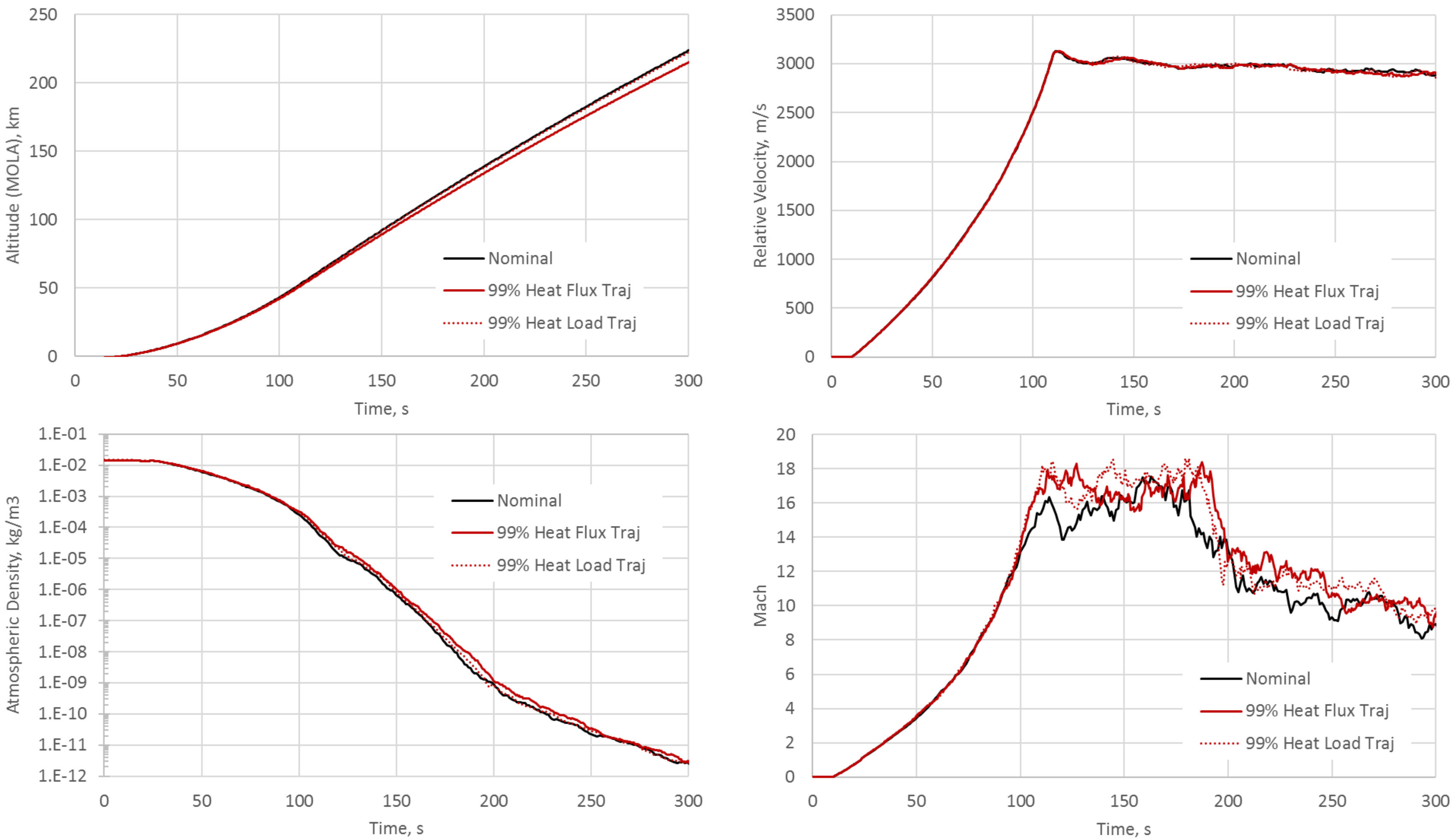
MAV Point of Departure (PoD) Configuration



- Notional MAV uses a hybrid propulsion system with MON30 oxidizer and SP7 (wax-based) fuel
  - Allows for storage temperatures as low as -72C, reducing power requirements for an MSR Lander while on the surface of Mars

Ascent through Mars atmosphere and delivery of OS to orbit requires a robust MAV design

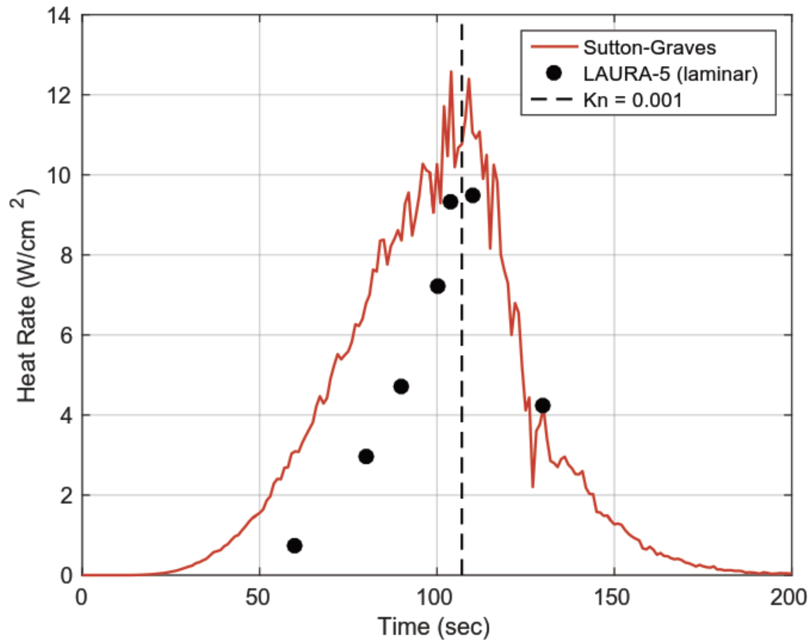
MAV Example Ascent Trajectories

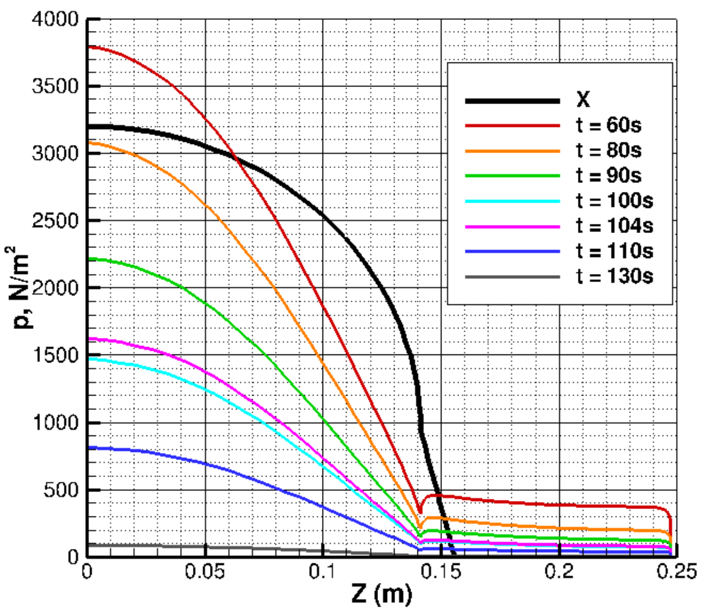


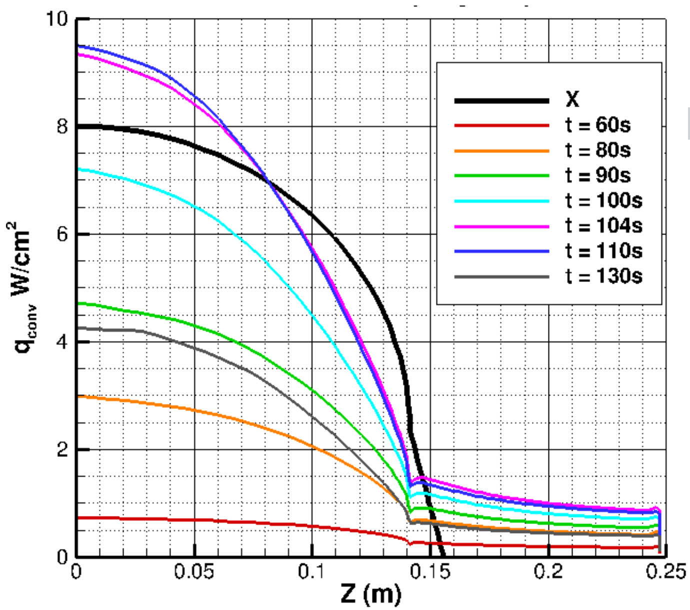
MAV ascent trajectory leads to different environments than typical entry

Ascent Aeroheating

- Heating based on 99% heat load trajectory
- CFD-based aerothermal environments
  - LAURA-5 code; axisymmetric geometry, laminar flow
  - Radiative equilibrium wall (ε = 0.8), super-catalytic
  - 8-species, one-temperature model







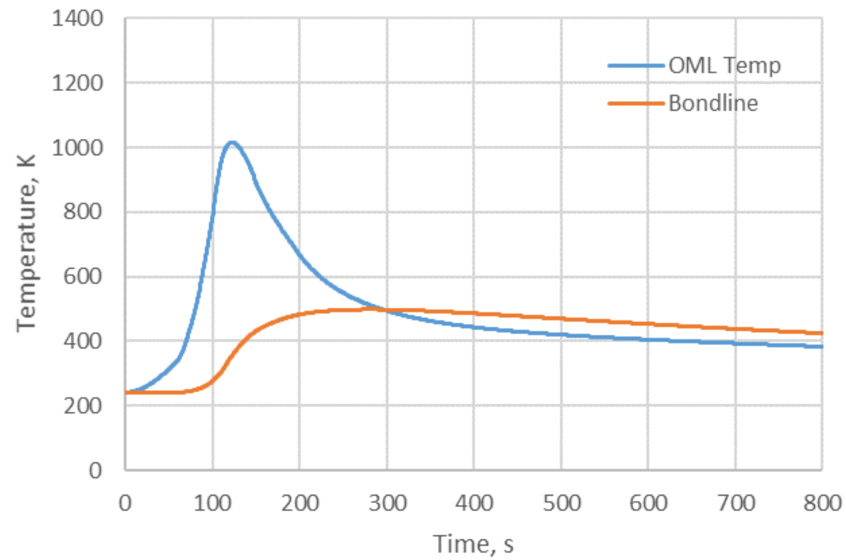
Heating is small relative to entry vehicles, but still requires consideration of TPS

TPS Design – PoD Design

- PoD TPS design assumed use of Shuttle tile material
  - TUFI-infiltrated FRCI-12 tile
    - TUFI provides impact resistance/robustness
    - Assumed 4 mm minimum thickness due to tile friability
  - RTV-560 adhesive
  - Composite substructure with standoffs
- 1D transient thermal analysis
  - CFD-based aerothermal environments w/25% margin

PoD TPS choice was primarily driven by handling considerations; thickness by manufacturability assumptions

TUFI: Toughened Unipiece Fibrous Insulation
FRCI: Fibrous Refractory Composite Insulation



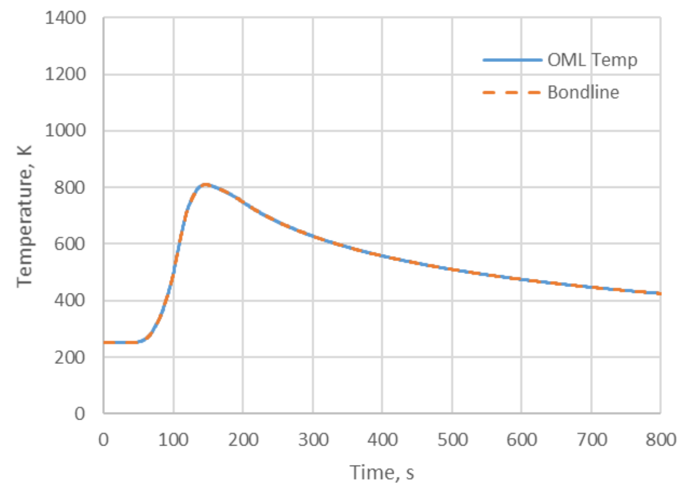
			TUFI / FRCI-12		
Dens	Mass	Vol		Tb	Tfinal
kg/m3	kg	m3		in	cm
1.31E+03	0.42713	3.26E-04	TUFI	0.1000	0.2540
1.92E+02	0.03498	1.82E-04	FRCI-12	0.0575	0.1460
1.43E+03	0.03584	2.51E-05	RTV-560	0.0080	0.0203
1.80E+03	0.43684	2.43E-04	Composite Substructure	0.0787	0.2000
		3.51E-04	standoff		0.3000
Total	0.93480	kg			
			Total Thickness		**0.9203**
				Current	Limit
			Peak Surface Temp, C	743	1482
			Peak Bondline Temp, C	225	312

Other TPS Material Options

- Currently investigating standoff TPS design using high-temperature metallic materials
  - Potential benefits in manufacturability and robustness
  - Options analyzed so far: Beryllium, Niobium, Titanium, Inconel
- Also planning to assess Carbon/Carbon composite structures in near future as well

Beryllium TPS sizing example:

			Beryllium					
Dens	Mass	Vol		Tb	Tfinal	w/FoS	Mass	
kg/m3	kg	m3		in	cm	cm	kg	in
2.64E+03	0.04122	1.56E-05	AZ-2100-IECW White Paint	0.0050	0.0127	0.0127		0.0050
1.84E+03	0.40474	2.20E-04	Beryllium	0.0714	0.1812	0.1812		0.0714
			Standoff gap		0.3000	0.3000		
Total	0.44596 kg							
				Total Thickness	**0.4939**	**0.4939**		
				Current	Limit			
			Peak Surface Temp, K	811	1273	AZ-2100-IECW White Paint		
			Peak Bondline Temp, K	811	811	Beryllium		

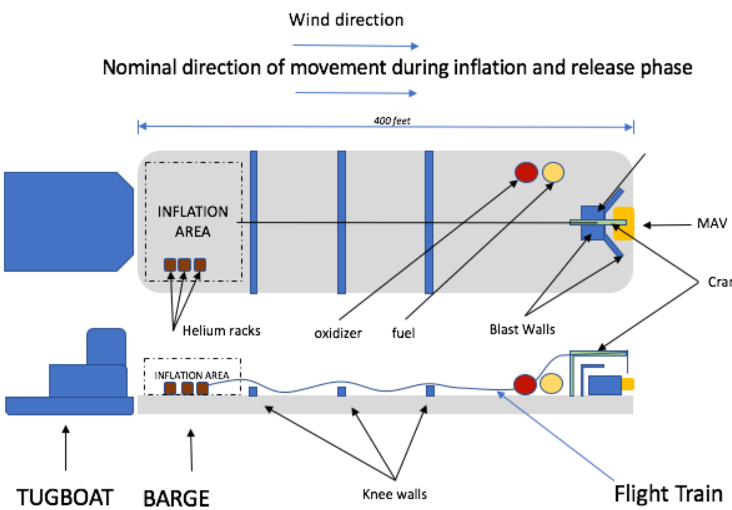


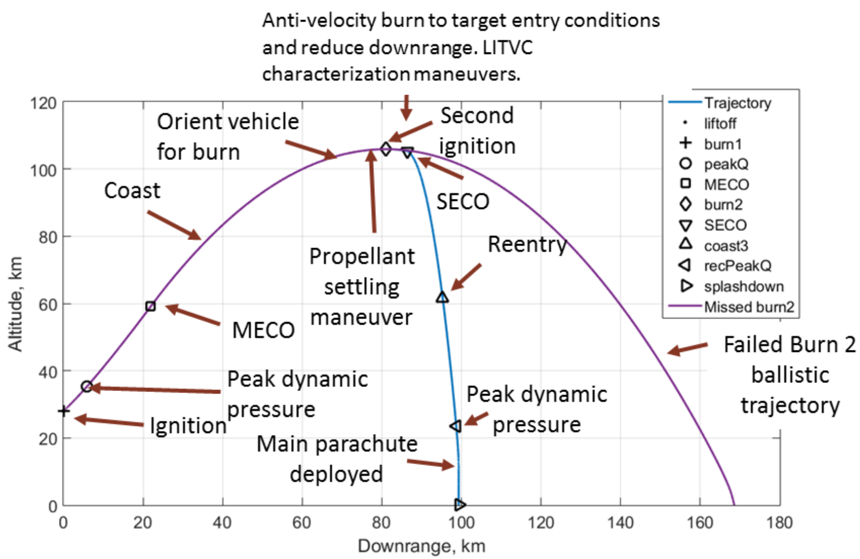
Conclusions and Future Work

- MAV design studies continuing
  - Trades/analyses (e.g., GN&C, propulsion)
  - Preparation for proposed Earth demo flight in 2019
- MAV aeroheating/TPS
  - Continue aeroheating trades/analyses
    - Revisit ejectable TPS for on-orbit thermal control
    - Sample tube loading approach vs. MAV/OS skirt design
  - Continue to assess TPS alternatives
    - Need material robustness yet low mass
    - On-orbit thermal considerations also important

Proposed MAV Tech Demo Plans

- Key objectives:
  - Measure environments at Mars-relevant conditions
  - Test out MAV technologies (e.g., LITVC, hybrid propulsion)
- Launch MAV vehicle from a high altitude balloon at ~30 km altitude
  - Balloon inflation and liftoff from a barge at sea
    - Barge is 400 ft long to accommodate flight train
  - Recovery of balloon and MAV demo vehicle





Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov